DESIGN AND FABRICATION OF

A LASER MODULATOR

Final Report

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Radio Corporation of America
Electronic Components and Devices
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Princeton, New Jersey

A LASER MODULATOR

The objective of the program was to develop a laser modulator capable of producing 40% depth of modulation for an applied voltage of 400 volts rms over a bandwidth from dc to 6 Mc/s. The program was a parallel effort on both Gallium Arsenide and Gallium Phosphide electro-optic crystals. In addition, some work was done on Potassium Tantalate Niobate (KTN) near the end of the program.

The theory of the linear electro-optic effect in Zincblende crystals such as Gallium Arsenide and Gallium Phosphide is described in the attached paper "Cuprous Chloride Light Modulators" by Sterzer, Blattner, and Miniter[1]. The theory of the quadratic electro-optic effect in perovskite crystals such as KTN is described by Geusic, et al[2].

The Gallium Arsenide crystals were grown by the horizontal Bridgeman technique[3] from elemental Gallium and Arsenic. The Gallium Phosphide crystals were grown both by the Czochralski technique from elemental Gallium in a Phosphorous atmosphere,[4] and by the vapor deposition technique[5] using Gallium Chloride and Phosphine in a Hydrogen carrier gas. The KTN crystal was grown by the Czochralski technique in a Platinum boat from Potassium Carbonate, Tantalum Pentoxide, and Niobium Pentoxide[2].

The best modulator crystal produced under this program was a Gallium Arsenide crystal which was incorporated into the modulator shown in Figures 1 and 2, which operated in the wavelength range from 0.9 to 3.0 microns. The modulator gave over 50% depth of modulation for 400 volts rms modulation signal, from dc to over 20 Mc/s. The performance curves of the modulator are shown in Figures 3 and 4. A paper(6) describing this modulator will be presented at the 1965 International Solid State Circuits Conference at Philadelphia in February 1966. A summary of the paper is attached to this report. The electro-optic coefficient, r_{41}, of Gallium Arsenide was measured in the set-up shown in Figure 5 and results are plotted in Figure 6.

The upper limit of three microns in the operating wavelength is caused by absorption in the Calcite Glan Thompson polarizers. The Gallium Arsenide crystal itself is transparent out to 16 microns, as shown in Figures 7 and 8, and could be used for modulation at these longer wavelengths provided suitable polarizers and quarter-wave plates could be obtained.

The transmission range of Gallium Phosphide is shown in Figures 7 and 8. The short wavelength cut-off occurs at 6000 Å, making it potentially useful for modulating visible lasers, such as the Helium-Neon laser at 6328 Å. The Gallium Phosphide crystals grown under this contract were of good optical quality, and took a good optical polish, but their resistivity was too low for modulation purposes. Several attempts were made to compensate the crystals by diffusion of Copper, a technique which produces high resistivity Gallium Arsenide(3), but no crystals were obtained which could withstand more than 30 volts before drawing excessive current.

In addition to the effort on Gallium Phosphide, a crystal of KTN was grown, cut, polished, and electroded. The transmission of KTN extends throughout the visible and near infrared, as shown in

Figures 7 and 8. The Curie point of the crystal was slightly above room temperature, and consequently it had to be heated slightly to operate in the paraelectric phase. The crystal showed a good deal of strain, but a sizeable electro-optic effect could be observed visually when 300 volts were applied; the magnitude of the effect depending on how close the crystal temperature was to the Curie point. Although the crystal was transparent, it scattered a laser beam so badly that no attempt was made to incorporate it into a modulator.

In addition, the crystal exhitited many piezoelectric resonances, which would cause severe distortion in a baseband modulation system. Subcarrier modulation would be required to raise the modulation spectrum frequencies above the piezoelectric resonant frequencies.

Of the three materials investigated, Gallium Arsenide is the most useful for laser modulation because of the advanced state of its crystal technology. It has the potential to modulate at wavelengths as great as 16 microns and it should be the first choice for these long wavelength applications. At visible wavelengths, KTN has the advantage over Gallium Phosphide of having a higher resistivity, shorter wavelength cut-off in the visible, and larger electro-optic effect. It has the disadvantages of requiring temperature control and having many piezoelectric resonances. The resistivity of Gallium Phosphide can probably be raised considerably with a compensating dopant, although none is known at the present. KTN and Gallium Phosphide both require more development to produce crystals with the excellent optical properties of existing Gallium Arsenide.

REFERENCES

1 F. Sterzer, D. J. Blattner, and S. F. Miniter, J. Opt. Soc. Am. 47, 1024 (1957).

2 J. E. Geusic, S. K. Kurtz, L. G. Van Uitert, and S. H. Wemple, App. Phys. Lett. 4, 141 (15 Apr. 1964).

3 J. Blanc, R. H. Bube, and H. E. MacDonald, J. App. Phys. 32, 1666 (1961).

4 C. J. Frosch and L. Derick, J. Electrochem. Soc. 108, 251 (1961).

5 J. A. Amick, RCA Review 24, 555 (1963).

6 T. E. Walsh, 1966 International Solid State Circuits Conference Record.

LIST OF ILLUSTRATIONS

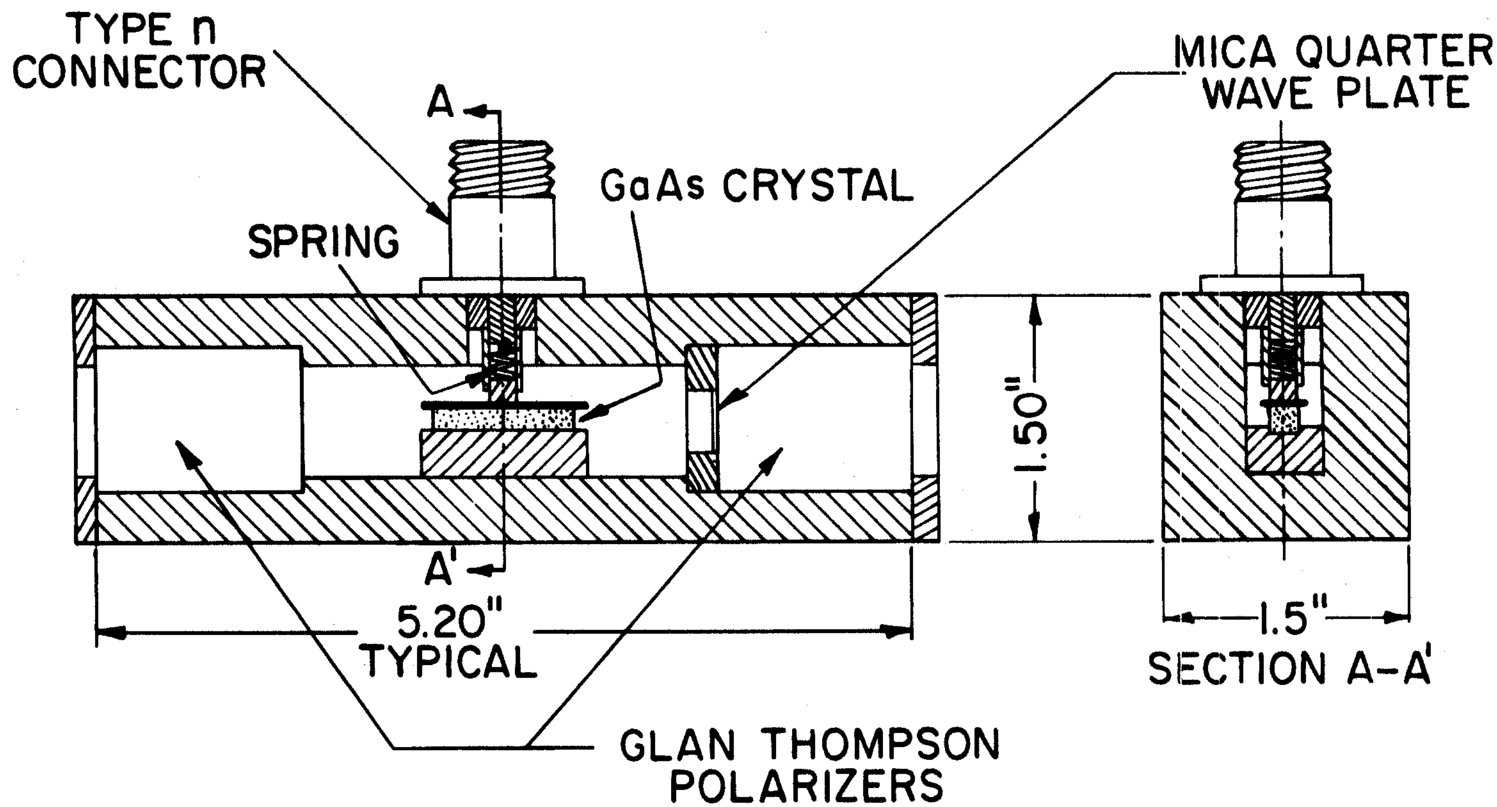

Fig. 1 — RCA J-2036 Solid-State Electro-Optic Modulator. Cross section.

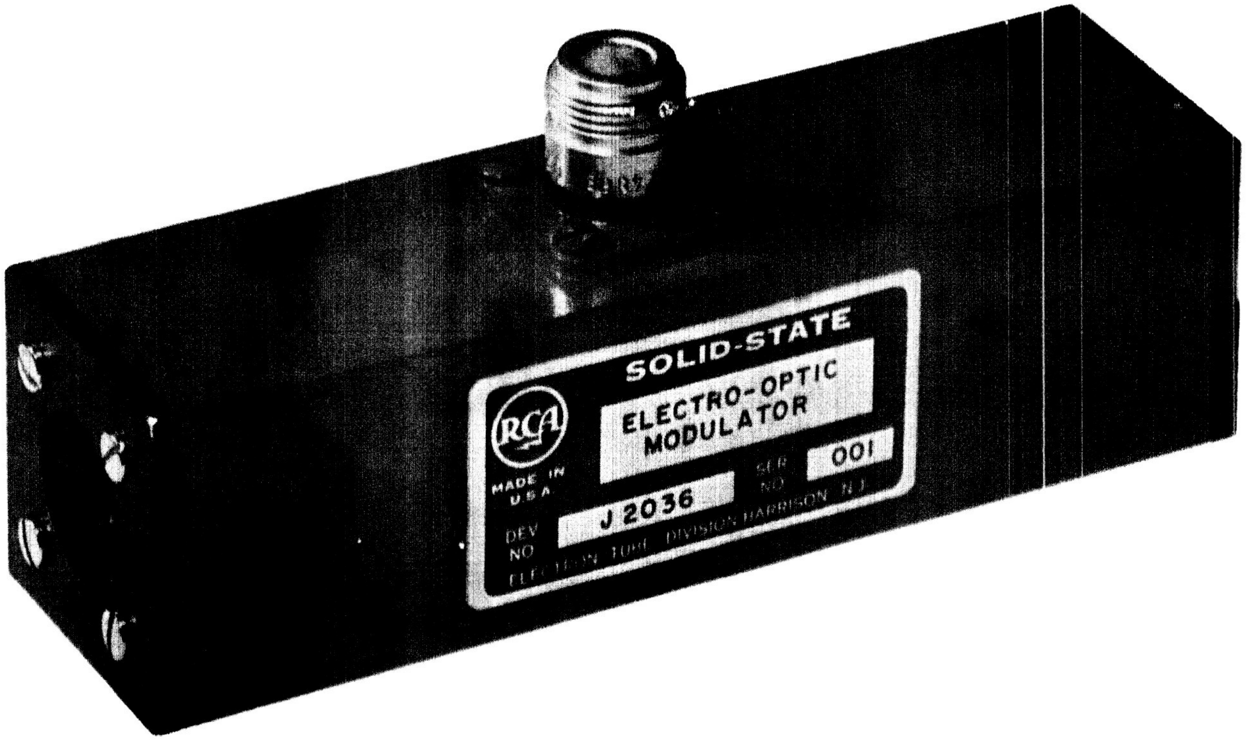

Fig. 2 — RCA J-2036 Solid-State Electro-Optic Modulator.

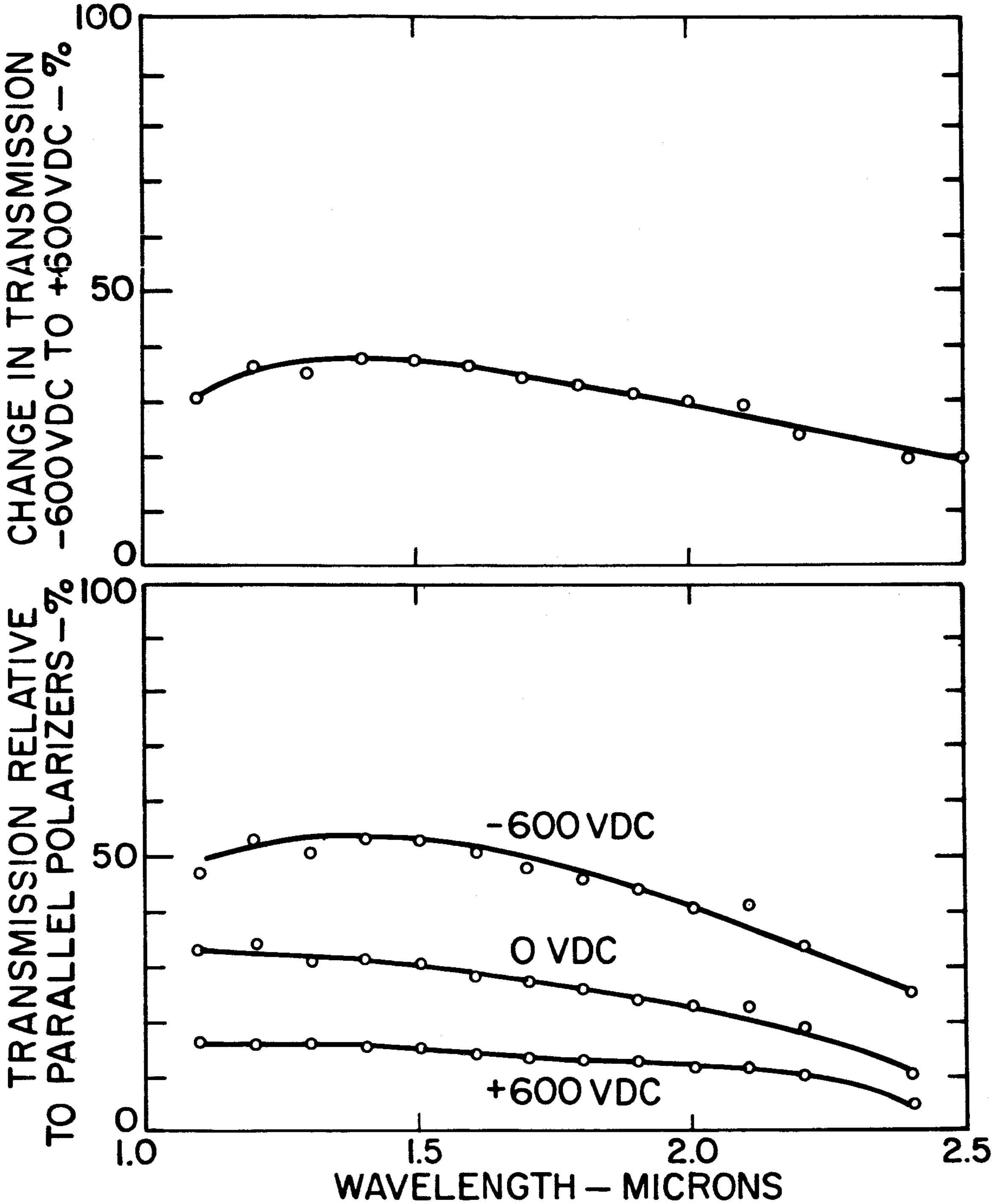

Fig. 3 — RCA J-2036 Solid-State Electro-Optic Modulator. Performance with 1.2 micron.

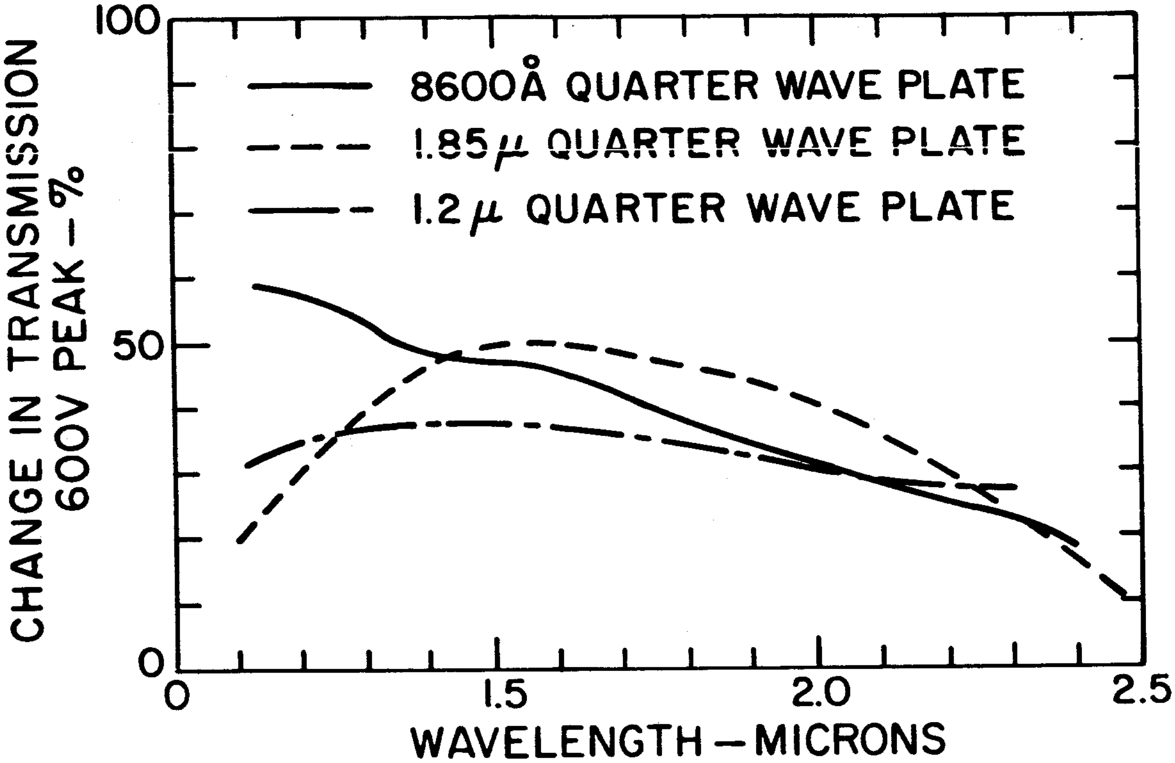

Fig. 4 — RCA J-2036 Solid-State Electro-Optic Modulator. Performance with different quarter-wave plates. These graphs correspond to the upper graph of Fig. 3.

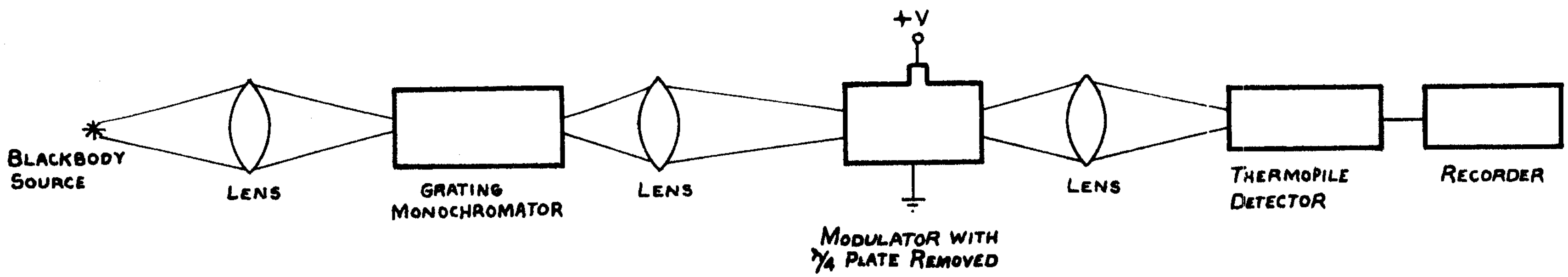

Fig. 5 — Experimental set-up for measurement of r_{41}.

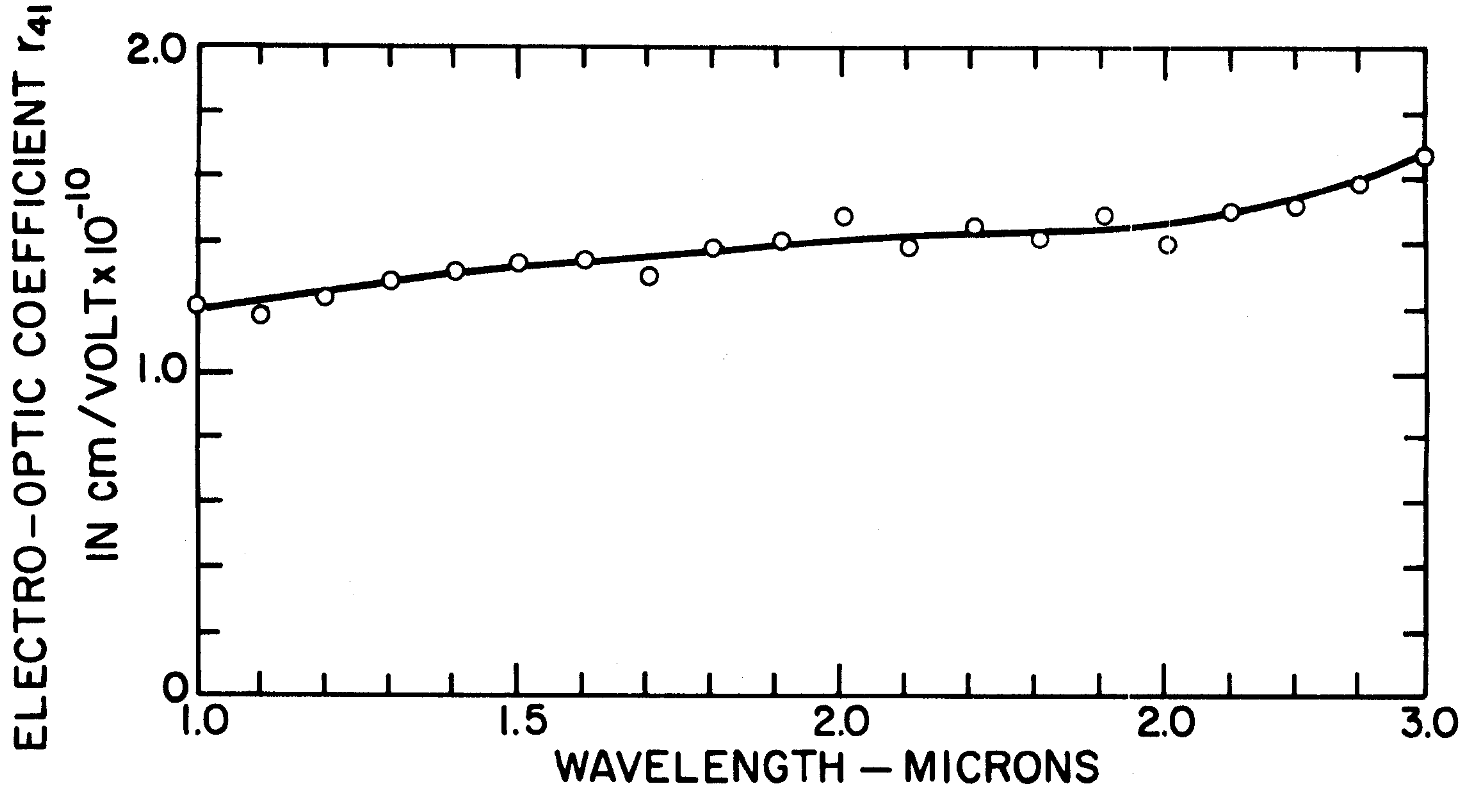

Fig. 6 — Electro-optic coefficient r_{41} versus wavelength.

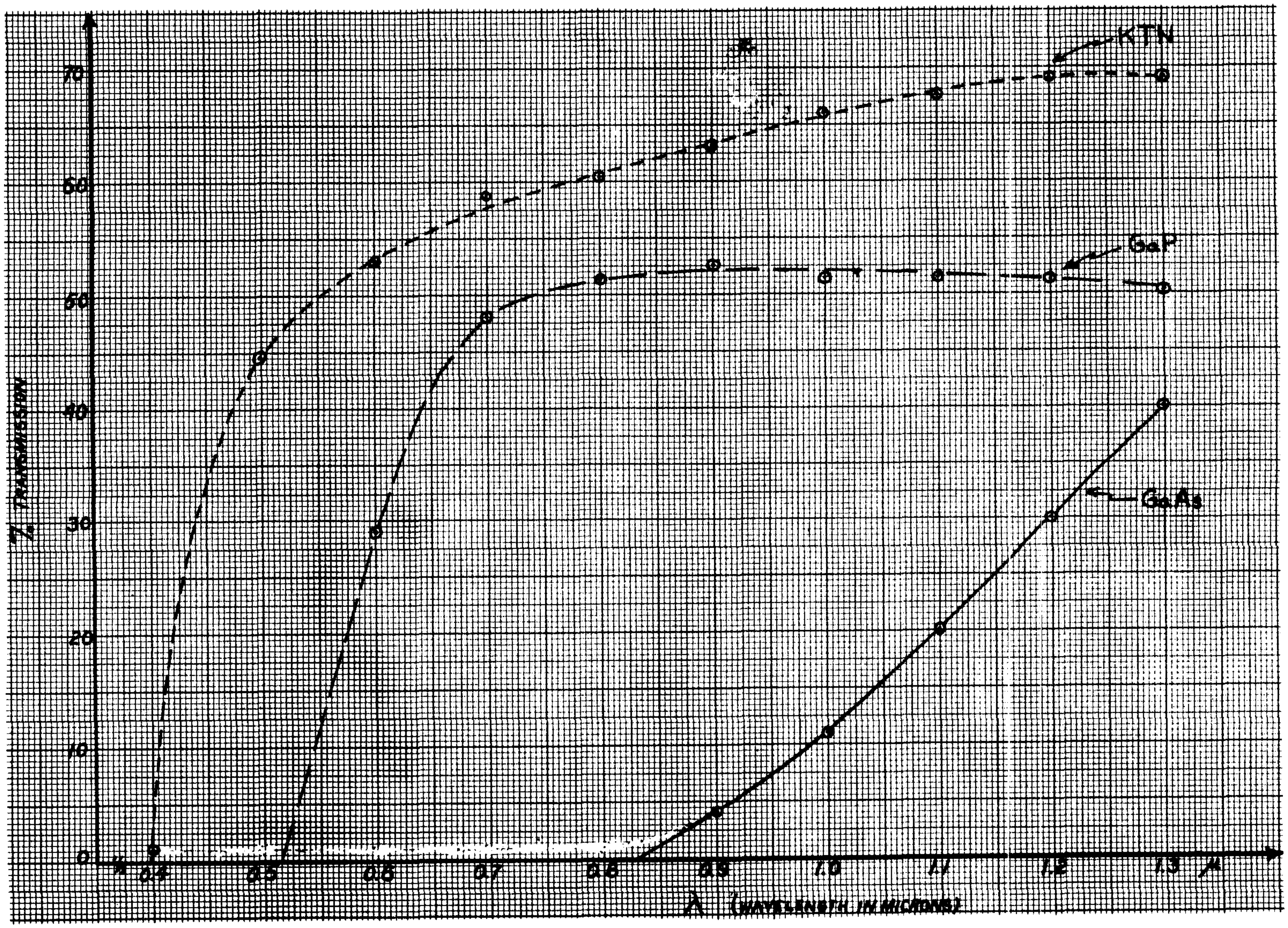

Fig. 7 — Transmittance of KTN, GaAs, and GaP.

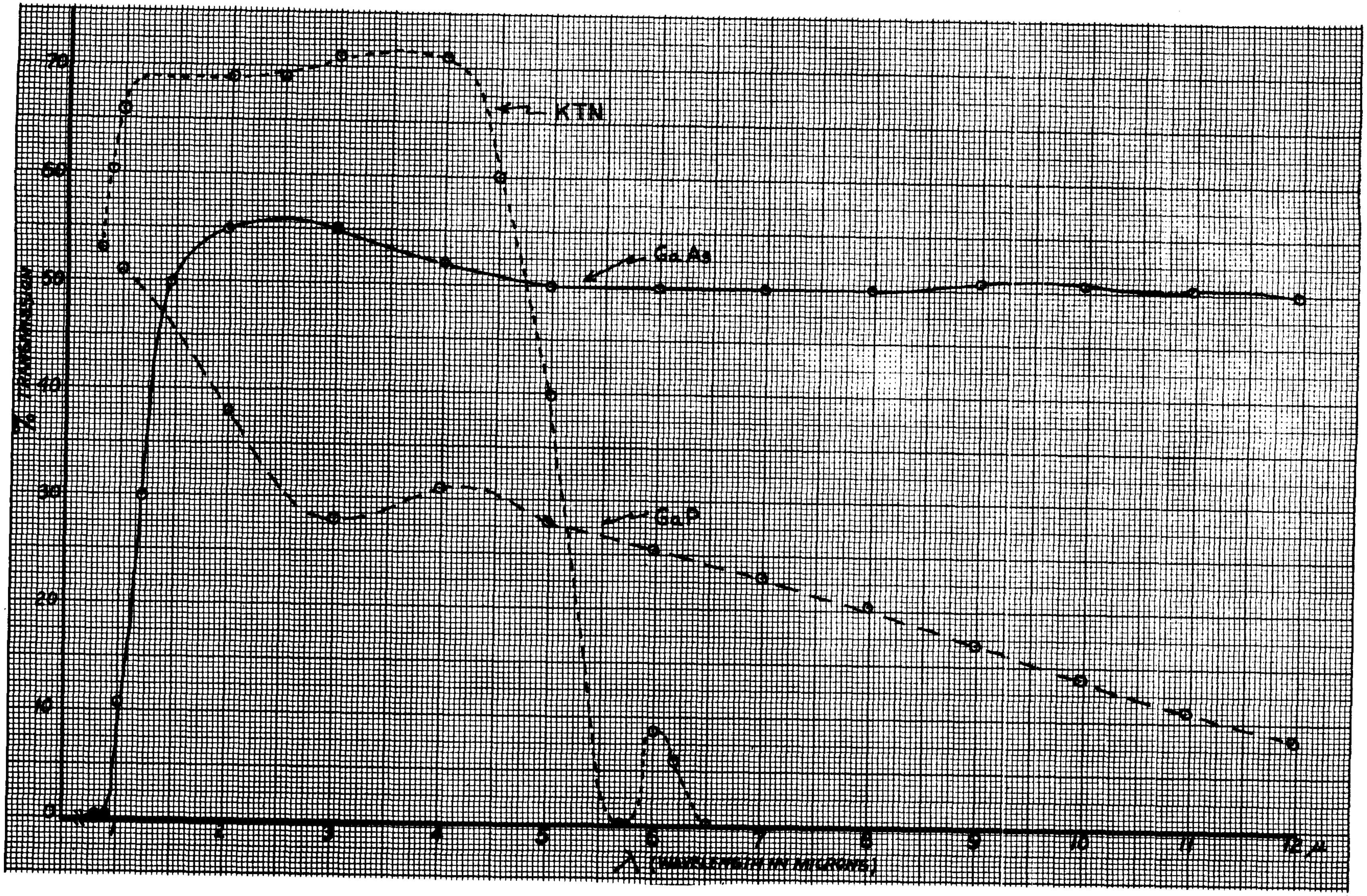

Fig. 8 — Transmittance of KTN, GaAs, and GaP.

Gallium Arsenide Infrared Modulators*

by

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609-452-2700

* The work reported here was sponsored by the Air Force Avionics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, under Contract No. AF33(615)-1096 and by the National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland, under Contract NAS-5-9620.

ABSTRACT OF PAPER FOR 1966

INTERNATIONAL SOLID STATE CIRCUITS CONFERENCE

Gallium Arsenide Infrared Modulators*

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GaAs electro-optic modulators having a linear aperture of 3 mm x 3 mm and an angular aperture greater than 12 degrees are described. In the wavelength range from one to three microns modulation depths in excess of 50% are achieved with 400 volts rms modulating signal from dc to beyond 20 Mc/s.

* The work reported here was sponsored by the Air Force Avionics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, under Contract No. AF33(615)-1096 and by the National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland, under Contract NAS-5-9620.

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Thomas E. Walsh - GaAs Modulators

SUMMARY

The small size and poor electrical and optical quality of most electro-optic crystals has limited their use as laser modulators. We have used large single crystals of Gallium Arsenide with excellent optical quality and uniformly high resistivity to construct practical electro-optic modulators for the infrared.

Gallium Arsenide is a hard, non-hygroscopic crystal which exhibits a linear electro-optic effect and is transparent between 0.9 and 16 microns in the infrared. Strain free Gallium Arsenide can be grown in seeded ingots with resistivities exceeding 10^6 ohm cm. The crystals are easily polished to better than one-tenth wavelength of visible light without introducing appreciable strain. Figure (1) illustrates the infrared transparency and optical quality of these crystals. It is an infrared photograph taken with an image converter tube of a sample of Gallium Arsenide on a metal scale. The quality is comparable to that of good optical glass.

Figure (2) shows a complete modulator consisting of a Gallium Arsenide crystal and a mica quarter-wave plate placed between two calcite Glan Thompson polarizers. The Gallium Arsenide crystal is mounted on the end of a 50 ohm coaxial line and presents a 3 picofarad capacitive load to the line. The openings in the mount for passage of the laser beam are cut-off waveguides at the modulation frequencies to prevent radiation of the modulating signal. The angular aperture is limited by the size of the Glan Thompson

polarizers which have a 1 cm aperture. The performance of the modulator with a 1.2 micron quarter-wave plate is illustrated in Figure (3), which shows the change in transmission produced by a 600 volt peak signal. The wavelength response of the modulator can be shaped by using different wave plates. Figure (4) shows the change in transmission produced by a 600 volt signal when different wave plates are used.

The electro-optic coefficient r_{41} was measured as a function of wavelength and found to be relatively constant (Figure 5), indicating that the operating wavelength can be increased at the expense of a proportionate increase in the operating voltage.

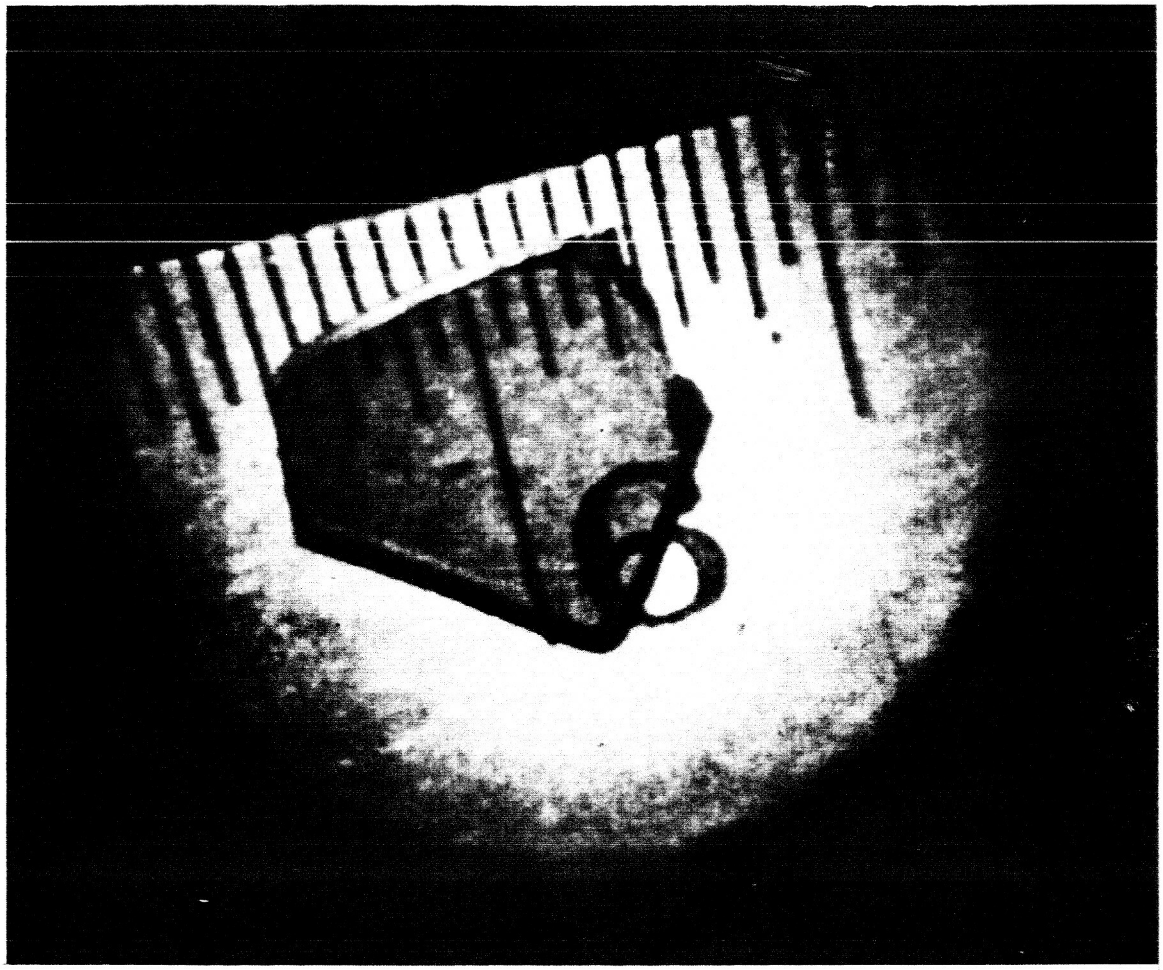

Fig. A-1 — Infrared photograph of GaAs crystal resting on scale.

Fig. A-2 — RCA J-2036 Solid-State Electro-Optic Modulator.

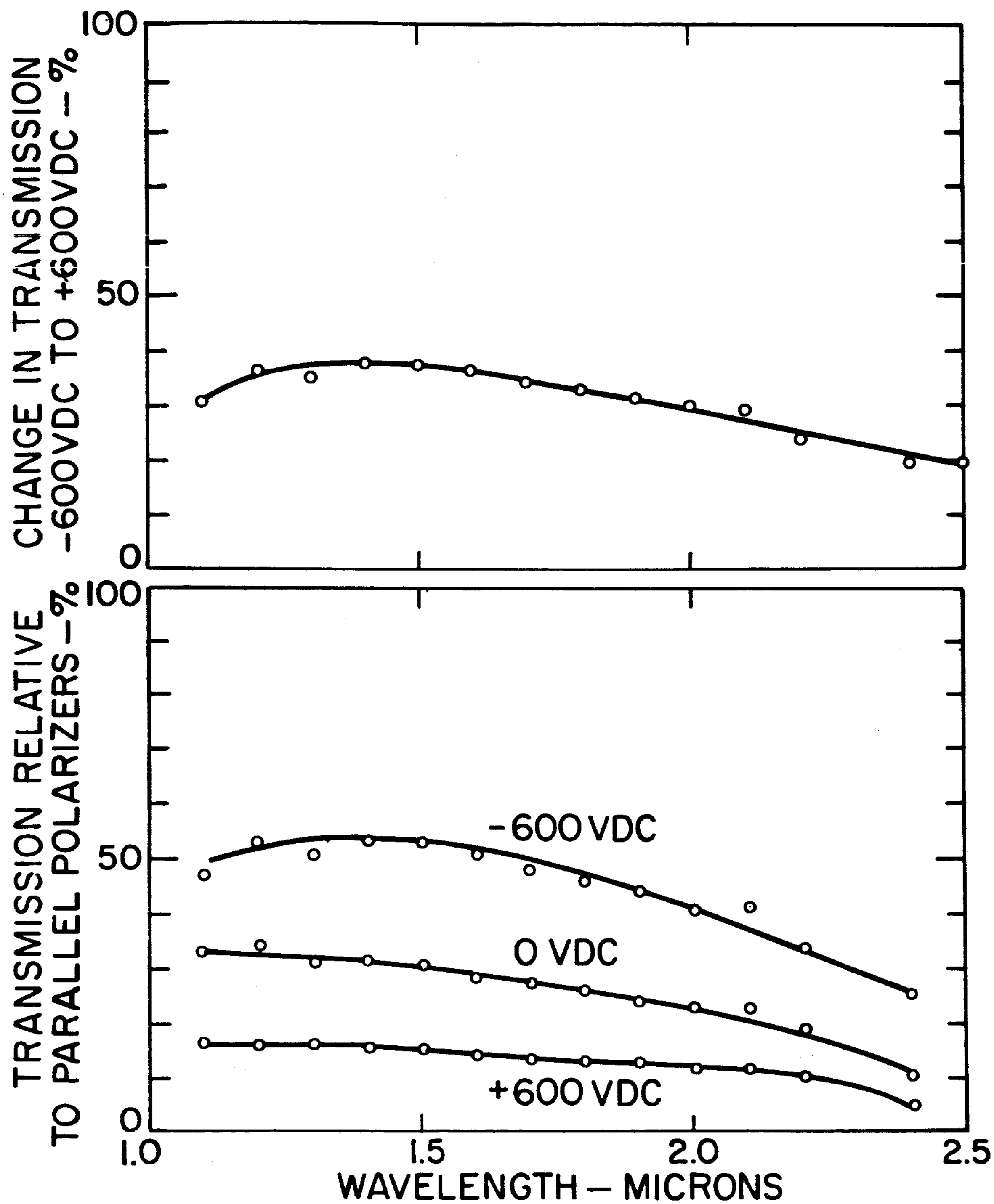

Fig. A-3 — RCA J-2036 Solid-State Electro-Optic Modulator. Performance with 1.2 micron.

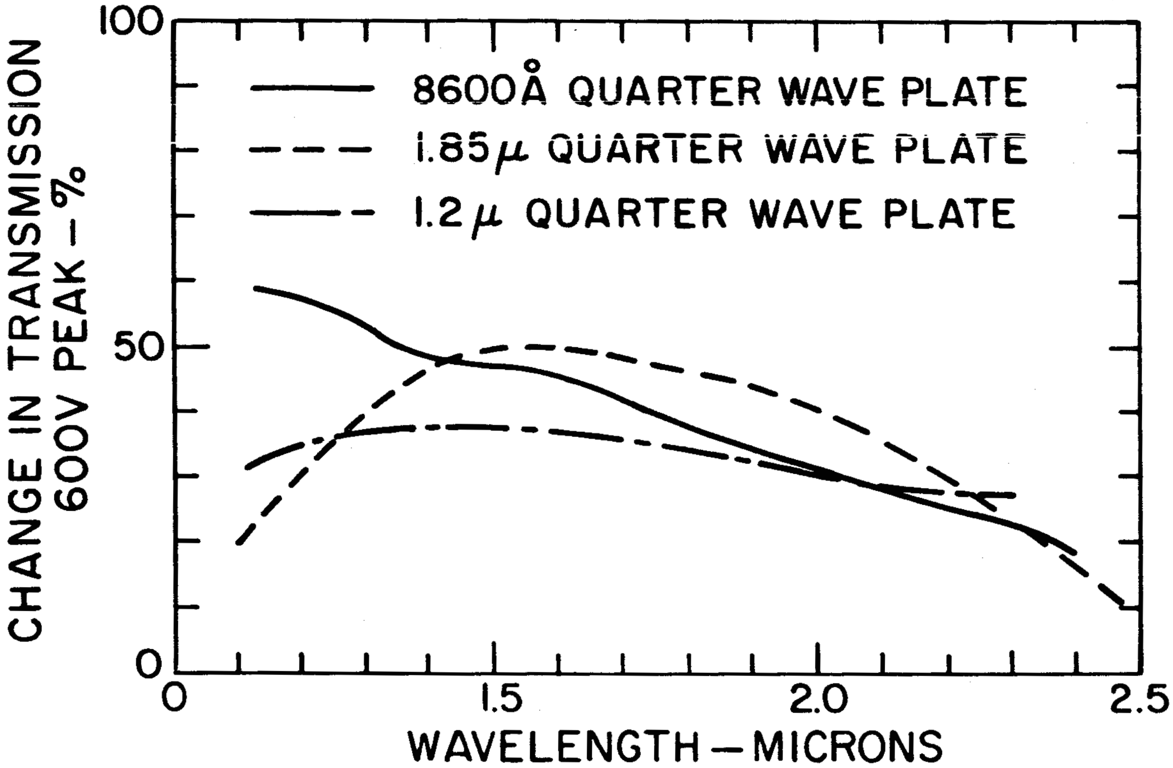

Fig. A-4 — RCA J-2036 Solid-State Electro-Optic Modulator. Performance with different quarter-wave plates. These graphs correspond to the upper graph of Fig. A-3.

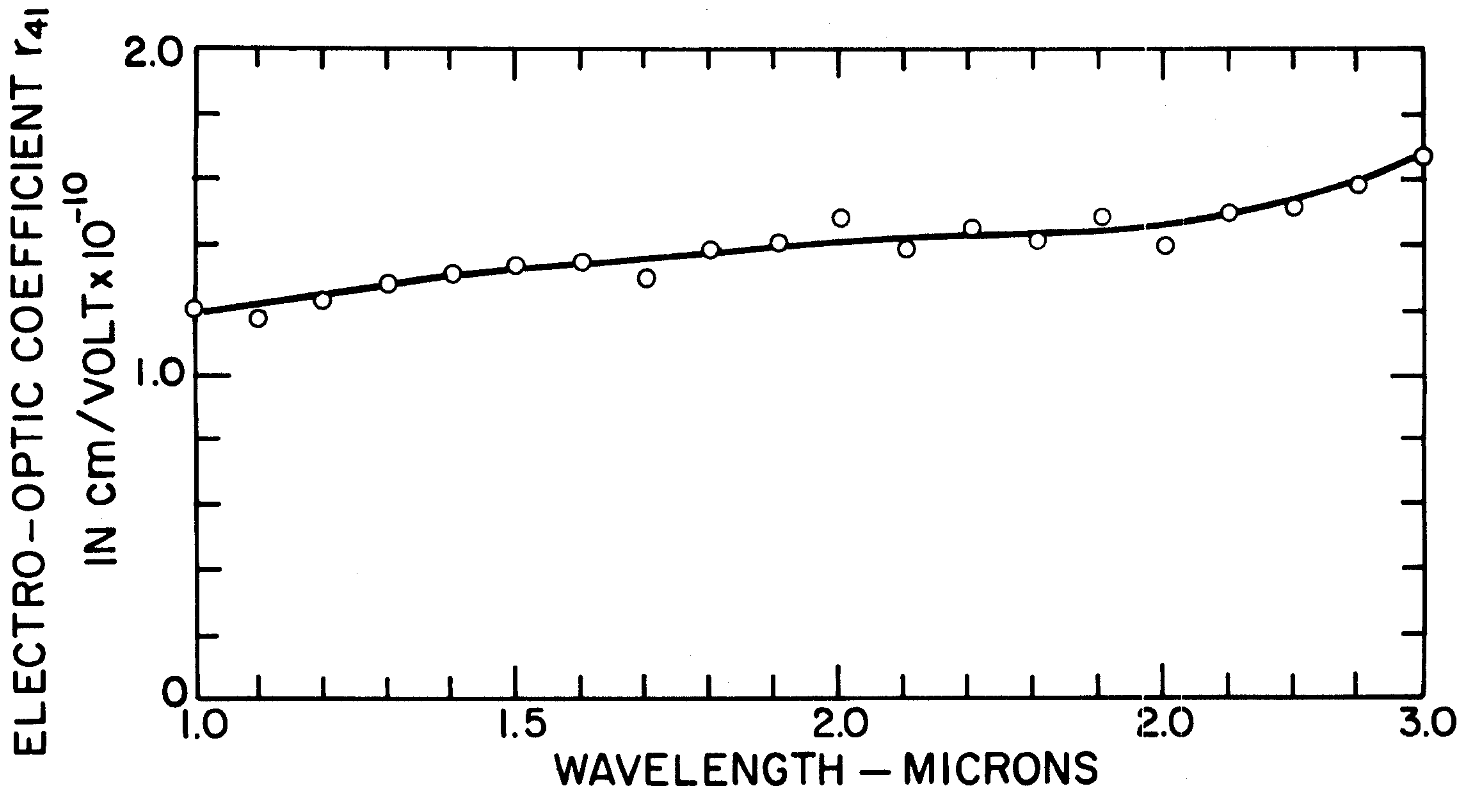

Fig. A-5 — Electro-optic coefficient r_{41} versus wavelength.